Module 1

Introduction

Lesson
1
Introducing the Course on Basic Electrical

Contents

Introduction

Welcome to this course on **Basic Electrical Technology**. Engineering students of almost all disciplines has to undergo this course (name may be slightly different in different course curriculum) as a core subject in the first semester. It is needless to mention that how much we are dependent on electricity in our day to day life. A reasonable understanding on the basics of applied electricity is therefore important for every engineer.

Apart from learning d.c and a.c circuit analysis both under steady state and transient conditions, you will learn basic working principles and analysis of transformer, d.c motors and induction motor. Finally working principles of some popular and useful indicating measuring instruments are presented.

The course can be broadly divided into 3 major parts, namely: Electrical circuits, Electrical Machines and Measuring instruments. The course is spread over 10 modules covering these 3-parts, each module having two or more lessons under it as detailed below.

Contributors

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Module-1 Introduction

Following are the two lessons in this module.

1.1 Introducing the course

Currently we are in this lesson which deals with the organization of the course material in the form of modules and lessons.

1.2 Generation, transmission and distribution of electric power: an overview

This lesson highlights conventional methods of generating 3-phase, 50 Hz electrical power, its transmission and distribution with the help of transmission lines and substations. It will give you a feel of a modern power system with names and function of different major components which comprise it.

Module-2 DC circuits

This module consists of seven lessons (2.1-2.7) starting with the fundamental concepts of electric circuit (active and passive) elements, circuit laws and theorems that established the basic foundation to solve dc network problems or to analyze the voltage, current and power (delivered or absorbed) in different branches. At the end of each lesson a set of problem is provided to test the readers understanding. Answers to these problems are located therein. The contents of each lesson are described below.

2.1 Introduction to electrical circuits

This lesson provides some basic concepts on Kirchoff's law, difference between linear and nonlinear circuits, and understanding the difference between current and voltage sources. The mathematical models of voltage and current sources are explained and subsequently the basic principles of voltage and current dividers are discussed. Each topic of this lesson is clearly illustrated by solving some numerical problems.

2.2 Loop Analysis of resistive circuit in the context of dc voltages and currents

In this lesson, loop analysis method based on Ohms law and Kirchoffs voltage law is presented to obtain a solution of a resistive network. This technique is particularly effective when applied to circuits containing voltage sources exclusively; however, it may be applied to circuits containing both voltage and current sources. Several numerical problems including both voltage and current sources have been considered to illustrate the steps involved in loop analysis method.

2.3 Node-voltage analysis of resistive circuit in the context of dc voltages and currents

Node voltage analysis is the most general and powerful method based on Kirchhoff's current law is introduced in this lesson for the analysis of electric circuits. The choice of one the nodes as reference node for the analysis of dc circuit is discussed. The procedure for analyzing a dc network is demonstrated by solving some resistive circuit problems.

2.4 Wye (*Y*) – Delta (Δ) or Delta (Δ) – Wye (*Y*) transformations

The objective of this lesson is to introduce how to convert a three terminal Delta (Δ) / Wye (*Y*) network into an equivalent Wye (Y) / Delta (Δ) through transformations. These are all useful techniques for determining the voltage and current levels in a complex circuit. Some typical problems are solved to familiarize with these transformations.

2.5 Superposition Theorem in the context of dc voltage and current sources acting in a resistive network

This lesson discusses a concept that is frequently called upon in the analysis of linear circuits (See 2.3). The principle of superposition is primarily a conceptual aid that can be very useful tool in simplifying the solution of circuits containing multiple independent voltage and current sources. It is usually not an efficient method. Concept of superposition theorem is illustrated by solving few circuit problems.

2.6 Thevenin's and Norton's theorems in the context of dc voltage and current sources in a resistive network

In this lesson we consider a pair of equivalent circuits, called Thevenin's and Norton's forms, containing both resistors and sources at the heart of circuit analysis. These theorems are discussed at length and highlighted their great utility in simplifying many practical circuit problems.

Reduction of linear circuits to either equivalent form is explained through solution of some circuit problems. Subsequently, the maximum power transfer to the load from the rest of circuit is also considered in this lesson using the concept of these theorems.

2.7 Analysis of dc resistive network in presence of one non-linear element

Volt-ampere characteristic of many practical elements (Carbon lamp, Tungsten lamp, Semiconductor diode, Thermistor etc.) exhibits a nonlinear characteristic and it is presented in this lesson. A common graphical procedure in case of one nonlinear element or device in a circuit is also introduced in this lesson to analyze the circuit behavior. This technique is also referred to as load line analysis method that is intuitively appealing to analyze some complex circuits. Another method based on analytic technique is described to analyze an electric circuit that contains only one nonlinear element or device. These techniques are discussed through worked out problems.

Module-3 DC transient

The study of DC transients is taken up in module-3, consisting of two lessons (3.1 and 3.2). The transients in a circuit containing energy storage elements occur when a switch is turned on or off and the behavior of voltage or a current during the transition between two distinct steady state conditions are discussed in next two lessons. At the end of each lesson some problems are given to solve and answers of these problems are located therein. The contents of each lesson are described below.

3.1 Study of DC transients in R-L and R-C circuits

This lesson is concerned to explore the solution of first order circuit that contains resistances, only single energy storage element inductance or capacitance, dc voltage and current sources, and switches. A fundamental property of inductor currents and capacitor voltages is discussed. In this lesson, the transient and steady state behavior in a circuit are studied when a switch is turned on or off. The initial condition, the steady solution and the time constant of the first order system are also discussed that uniquely determine the system behavior. The solution of differential equation restricted to second order dynamic systems for different types of forcing function are included in Appendix of this, lesson. Some problems are solved and their dynamic responses are plotted.

3.2 Study of DC transients in R-L-C circuits

The solution of second order circuit that contains resistances, inductances and capacitances, dc voltage and current sources, and switches is studied in this lesson. In this lesson, the transient and steady state behavior of a second order circuit are studied under three special cases namely, (i) over damped system (ii) critically damped system (iii) under damped system that can arise depending upon the values of circuit parameters. Some examples are solved and their dynamic responses are shown.

Module-4 Single phase AC circuits

There are six lessons (4.1-4.6) in this module, where the various aspects related to ac circuits fed from single phase supply, are described.

4.1 Generation of single phase ac and fundamental aspects

The principle of generation of sinusoidal (ac) waveforms (single phase) in an ac generator is first presented. Then, the two aspects – average and root mean square (rms) values, of alternating or periodic waveforms, such as voltage/current, are described with typical examples (sinusoidal and triangular).

4.2 Representation of sinusoidal quantities in phasor with j operator

As the phasor relations are widely used for the study of single phasor ac circuits, the phasor representation of sinusoidal quantities (voltage/current) is described, in the lesson, along with the transformation from rectangular (Cartesian) to polar form, and vice versa. Then, the phasor algebra relating the mathematical operations, involving two or more phasors (as the case may be), from addition to division, is taken up, with examples in each case, involving both the forms of phasor representations as stated.

4.3 Steady state analysis of series circuits

The steady state analysis of series (R-L-C) circuits fed from single phase ac supply is presented. Staying with each of the elements (R, L & C), the current in steady state is obtained with application of single phase ac voltage, and the phasor diagrams are also drawn in each case. The use of phasor algebra is also taken up. Then, other cases of series circuits, like R-L, R-C and R-L-C, are described, wherein, in each case, all methods as given, are used.

4.4 Analysis of parallel and series-parallel circuits

The application of phasor algebra to solve for the branch and total currents and the complex impedance, of the parallel and the series-parallel circuits fed from single phase ac supply is presented in this lesson. The phasor diagram is drawn showing all currents, and voltage drops. The application of two Kirchoff's laws in the circuits, for the currents at a node, and the voltage drops across the elements, including voltage source(s), in a loop, is shown there (phasor diagram).

4.5 Resonance in electrical circuits

The problem of resonance in the circuits fed from a variable frequency (ac) supply is discussed in this lesson. Firstly, the case of series (R-L-C) circuit is taken up, and the condition of resonance, along with maximum current and minimum impedance in the circuit, with the variation in supply frequency is determined. Then, the problem of parallel circuits and other cases, such as, lossy coil (r-L), is taken up, where the condition of resonance is found. This results in minimum current and maximum impedance here.

4.6 Concept of apparent, active and reactive power

The formula for active (average) power in a circuit fed from single phase ac supply, in terms of input voltage and current, is derived in this lesson, followed by definition of the term, 'power factor' in this respect. The concept of apparent and reactive power (with its sign for lagging and leading load) is presented, along with formula.

Module-5 Three phase AC circuits

There are only three lessons (5.1-5.3) in this module. Only the balanced star-and delta-connected circuits fed from three-phase ac supply are presented here.

5.1 Generation of three-phase voltage, line and phase quantities in star- and delta-connection and their relations

The generation of three-phase balanced voltages is initially presented. The balanced windings as described can be connected in star- and delta-configuration. The relation between line and phase voltages for star-connected supply is presented. Also described is the relation between phase and line currents, when the windings are connected in delta. The phasor diagrams are drawn for all cases.

5.2 Solution of three-phase balanced circuits

The load (balanced) is connected in star to a balanced three-phase ac supply. The currents in all three phases are determined, with phasor diagram drawn showing all voltages and currents. Then, the relation between phase and line currents is derived for balanced delta-connected load. The power (active) consumed in the balanced load is derived in terms of the line voltage and currents for both cases.

5.3 Measurement of three-phase power

The total power (in all three phases) is measured using two wattmeters only. This is shown for both unbalanced and balanced cases. The phasor diagram with balanced three-phase load is drawn. Other cases are also described.

Module-6 Magnetic circuits & Core losses

In this module there are two Lessons 21 and 22 as enumerated below.

6.1 Simple magnetic circuits

It is often necessary to produce a desired magnetic flux, in a magnetic material (core) having a definite geometric shape with or without air gap, with the help of current passing through a coil wrapped around the core. This lesson discusses how the concept of circuit analogy can be introduced to tackle such problems. Both linear and non-linear magnetic circuit problems are discussed through worked out problems.

6.2 Eddy current & hysteresis losses

These two losses are produced in any magnetic material which is subjected to an alternating time varying fields. Generally in all types of A.C machines /equipments working on electromagnetic principle these losses occur. In D.C machine armature too these losses occur. In this lesson the origin of these losses are explained and formula for estimating them are derived. Finally methods adopted to minimize these losses discussed as losses bring down the efficiency of any machines.

Module-7 Transformer

Transformers are one of the most important components of the modern power system. In this module having 6 lessons, various aspects of a transformer are explained and discussed as per the break up given below.

7.1 Ideal single phase transformer

Clear concept of ideal transformer goes a long way to understand the equivalent circuit representation of a practical transformer discussed in the next lesson. In ideal transformer all kinds of losses are neglected and permeability of core is assumed to be infinitely large. To have a **rough** and quick estimate of primary current for a given secondary current of a practical transformer one need not consider detail equivalent circuit but rather pretend that the transformer is ideal and apply simple relation of ideal transformer.

Properties of ideal transformer and its principle of operation along with phasor diagram are discussed both under no load and load condition.

7.2 Practical single phase transformer

A practical transformer has various losses and leakage impedance. In this lesson, it has been shown how these can be taken into account in the equivalent circuit. Phasor diagrams under no load and load condition developed. Concept of approximate equivalent circuit discussed and meaning of equivalent circuit referred to primary and secondary side are explained.

7.3 Testing, efficiency and regulation of transformer

Two basic tests called *open circuit* and *short circuit* test are discussed and then it is explained how equivalent circuit parameters of a single phase transformer can be obtained from the test data. Importance of selecting a particular side for a particular test is highlighted.

Importance of efficiency and regulation are discussed and working formula for them derived. Concept of *all day* efficiency for distribution transformer is given. Regulation is essentially a measure of change of magnitude of the secondary voltage from no load to full load condition and its value should be low. From the expression of regulation it is easily identified the parameters on which it depends.

7.4 Three phase transformer

Generation, distribution and transmission of power are carried out with a 3-phase, 50 Hz system. Therefore, stepping up or down of 3-phase voltage is required. This of course can not be done using a single phase transformer. Three separate identical transformers can be connected appropriately to serve the purpose. A 3-phase transformer formed by connecting three separate transformers is called a *bank* of 3-phase transformer. Another way of having a three phase transformer, is to construct it as a single unit of three phase transformer. The relative advantages and disadvantages of the two are discussed.

Various important and popular connections of 3-phase transformer (such as star/star, star/delta, delta/star etc.) are discussed. The importance of dot convention while making such connections are pointed out. Simple problems involving a 3-phase transformer connection are worked out assuming the transformer to be ideal.

Vector grouping of various three phase transformer connection are generally not meant for a first year course and can be avoided. However, for completeness sake and for students who want to know more, it is included.

7.5 Autotransformer

There are transformers which work with a single winding. Such transformers are called auto-transformers. The lesson discusses its construction and bring out differences with *two winding* transformer. Here, ideal auto transformer is assumed to show how to find out current distribution in different parts of the winding when it is connected in a circuit. It is also pointed out how three single phase auto transformers can be connected to transform a 3-phase voltage.

7.6 Problem solving on transformers

Few typical problems on single phase, 3-phase and auto transformers are worked out, enumerating logical steps involved.

Module-8 Three phase induction motor

In this module consisting of six lessons (8.1-8.6), the various aspects of the three-phase induction motor are presented.

8.1 Concept of rotating magnetic field

Before taking up the three-phase induction motor (IM), the concept of rotating magnetic field is introduced in this lesson. The balanced three-phase winding of the stator in IM are fed from a balanced three-phase supply. It is shown that a constant magnitude of magnetic field (flux) is produced in the air gap, which rotates at 'synchronous speed' as defined in terms of No. of poles of the stator winding and supply frequency.

8.2 Brief construction and principle of operation

Firstly, the construction of a three-phase induction motor is briefly described, with two types of rotor – squirrel cage and wound (slip-ring) one. The principle of torque production in a three-phase IM is explained in detail, with the term, 'slip' defined here.

8.3 Per phase equivalent circuit and power flow diagram

The equivalent circuit of a three-phase IM is obtained, which is explained step by step. Also the power flow diagram and the various losses taking place are discussed.

8.4 Torque-slip (speed) characteristic

The torque speed (slip) equation is obtained from the equivalent circuit of the rotor. The characteristics are drawn, with typical examples, such as variation in input (stator) voltage, and also in rotor resistance (with external resistance inserted in each phase).

8.5 Types of starters

The need of starter in a three-phase IM to reduce the stating current drawn is first explained. Then, three types of starters – Direct-on-line (DOL), star-delta one for use in an IM with a nominally delta-connected stator, and auto-transformer, are described. Lastly, the rotor resistance starter for a wound rotor (slip ring) IM is briefly presented.

8.6 Single-phase induction motor and starting methods

It is first shown that starting torque is not produced in a single phase induction motor (IM). Then, the various types of starting methods used for single-phase IM with two stator windings (main and auxiliary), are explained in detail. Lastly, the shaded pole single-phase IM is described.

Module-9 DC Machines

9.1 Constructional features of DC machines

The lesson discusses the important construction features of DC machines. The induced voltage in a rotating coil in a stationary magnetic field is always alternating in nature. The functions of commutator segments and brushes, which convert the AC voltage to DC form, are explained.

The examples of lap and wave windings used for armature are presented. It has been shown that the number of parallel paths in the armature will be different in the two types of windings. For the first time reading and depending upon the syllabus, you may avoid this portion.

9.2 Principle of operation of D.C machines

The lesson begins with an example of *single* conductor linear D.C generator and motor. It helps to develop the concept of driving force, opposing force, generated and back emf.

Concept of Driving and opposing torques in rotating machines are given first and then the principle of operation of rotating D.C generator and motor are explained. Condition for production of steady electromagnetic torque are discussed.

9.3 EMF and torque equations

The derivation of the two basic and important equations, namely emf and torque equations, which are always needed to be written, if one wants to analyse the machine performance. Irrespective of the fact that whether the machine is operating as a generator or as a motor, the same two equations can be applied. This lesson also discusses armature reaction, its ill effects and methods to minimize them.

The topic of calculation of cross magnetizing and demagnetizing mmf's can be avoided depending upon the syllabus requirement and interest.

9.4 DC Generators

The lesson introduces the types of DC generators and their characteristics. Particular emphasis has been given to DC shunt and separately excited generators. The open circuit characteristic (O.C.C) and the load characteristics of both kinds are discussed. It is explained that from O.C.C and the field resistance line, it is possible to get graphically the load characteristic.

9.5 DC motor starting and speed control

In this important lesson, problem of starting a DC motor with full voltage is discussed, and the necessity of starter is highlighted. The operation of a three-point starter is explained. Various methods of controlling speed of DC shunt and series motors are discussed. At the end, a brief account of various methods of electrical braking is presented.

9.6 Losses, efficiency and testing of D.C machines

To calculate efficiency of any machines, it is essential to know various losses that take place in the machine. Major losses in a DC machine are first enumerated, and Swinburne's test and Hopkinson's tests are explained to estimate them.

9.7 Problem solving in DC machines

In this lesson, some typical problems of DC motors and generators are worked out. This lesson should be consulted from other relevant lectures of the present module whenever you feel it to be necessary.

Module-10 Measuring instruments

The magnitude of various electric signals can be measured with help of measuring instruments. These instruments are classified according to the quantity measured and the principle of operation. The study of DC and AC instruments for measuring voltage, current signals and subsequently induction type energy meter, are described in this module consisting of three lessons (10.1 10.3). at the end of each lesson (10.1 10.3), a set of problem is provided to test the readers understanding.

10.1 Study of DC and AC measuring instruments

The general theory of permanent magnet moving coil (PMMC), moving-iron (MI) instruments and their constructions are briefly discussed in this lesson. PMMC instruments are used as a dc ammeter or dc voltmeter where as MI instruments are basically used for ac current or voltage measurements. Various torques involved in measuring instruments are classified and explained. Subsequently, the advantages, limitations and sources of errors of these instruments are studied therein. Idea behind the multi-range ammeters and voltmeters are introduced by employing several values of shunt resistors or several multiplier resistors along with the meter resistance. In this context some problems are solved to illustrate the meaning of multi-range meters.

10.2 Study of electrodynamics type instruments

Electrodynamics meters can measure both dc signals and ac signals up to a frequency of. The basic construction of electro-dynamometer instruments and their principles of operation are studied in this lesson. Torque expressions for such instruments (as an ammeter, voltmeter and a wattmeter) are derived and then mode of meter connections to the load as an ammeter, voltmeter and a wattmeter are presented. Shunts and multipliers can be used for extension of meters range. A compensation technique is introduced to eliminate the errors in wattmeter readings. In this lesson, the constructional features and principle of operation of electro dynamometer instruments (ammeter, voltmeter and wattmeter) have been discussed. The sources of error and their corrections are highlighted. Some problems have been worked out for better understanding.

10.3 Study of single-phase induction type energy meter or watt-hour meter

The basic construction with different components of a single-phase induction type energy meter is considered in this lesson. Development of torque expression and errors in energy meters are studied. Some adjustment techniques are discussed to compensate the errors in energy meter. Finally, the extension of meter range using instrument transformers is discussed.

Module
1

Introduction

Lesson
2
Generation, Transmission and Distribution of Electric Power an Overview

Contents

Chapter 2

Generation, Transmission and Distribution of Electric Power (Lesson-2)

2.1 Goals of the lesson

After going through the lesson you shall get a broad idea of the following:

1. Different methods of generating electrical power.
2. Issues involved in transporting this power to different types of consumers located generally at far off places from the generating stations.
3. Necessity of substations to cater power to consumers at various voltage levels.

2.2 Introduction

In this lesson a brief idea of a modern power system is outlined. Emphasis is given to create a clear mental picture of a power system to a beginner of the course Electrical Technology. As consumers, we use electricity for various purposes such as:

1. Lighting, heating, cooling and other domestic electrical appliances used in home.
2. Street lighting, flood lighting of sporting arena, office building lighting, powering PCs etc.
3. Irrigating vast agricultural lands using pumps and operating cold storages for various agricultural products.
4. Running motors, furnaces of various kinds, in industries.
5. Running locomotives (electric trains) of railways.

The list above is obviously not exhaustive and could be expanded and categorized in detail further. The point is, without electricity, modern day life will simply come to a stop. In fact, the advancement of a country is measured by the index *per capita consumption of electricity* – more it is more advanced the country is.

2.3 Basic idea of generation

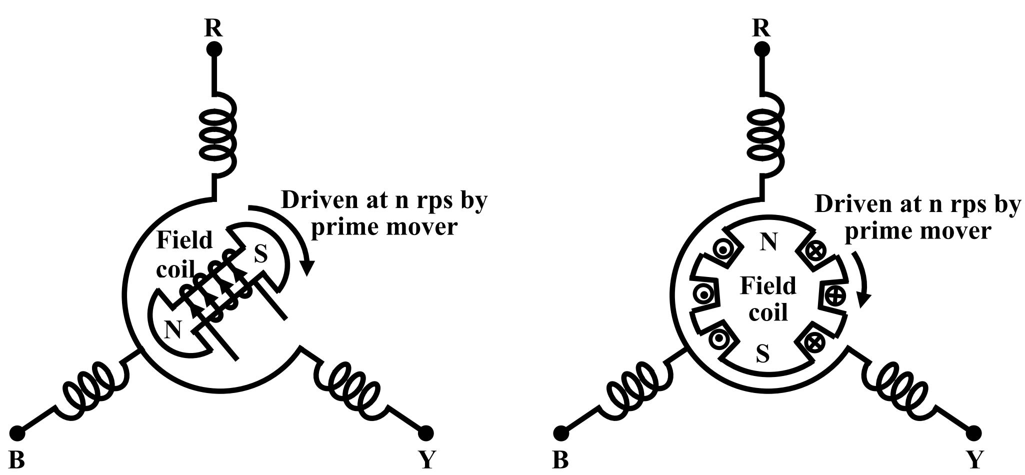
Prior to the discovery of Faraday's Laws of electromagnetic discussion, electrical power was available from batteries with limited voltage and current levels. Although complicated in construction, D.C generators were developed first to generate power in bulk. However, due to limitation of the D.C machine to generate voltage beyond few hundred volts, it was not economical to transmit large amount of power over a long distance. For a given amount of power, the current magnitude ($I = P/V$), hence section of the copper conductor will be large. Thus generation, transmission and distribution of d.c power were restricted to area of few kilometer radius with no interconnections between generating plants. Therefore, area specific generating stations along with its distribution networks had to be used.

2.3.1 Changeover from D.C to A.C

In later half of eighties, in nineteenth century, it was proposed to have a power system with 3-phase, 50 Hz A.C generation, transmission and distribution networks. Once a.c system was adopted, transmission of large power (MW) at higher transmission voltage become a reality by using *transformers*. Level of voltage could be changed virtually to any other desired level with transformers – which was hitherto impossible with D.C system. Nicola Tesla suggested that constructionally simpler electrical motors (induction motors, without the complexity of commutator segments of D.C motors) operating from 3-phase a.c supply could be manufactured. In fact, his arguments in favor of A.C supply system own the debate on switching over from D.C to A.C system.

2.3.2 A.C generator

A.C power can be generated as a single phase or as a balanced poly-phase system. However, it was found that 3-phase power generation at 50 Hz will be economical and most suitable. Present day three phase generators, used to generate 3-phase power are called *alternators* (synchronous generators). An alternator has a balanced three phase winding on the stator and called the armature. The three coils are so placed in space that there axes are mutually 120° apart as shown in figure 2.1. From the terminals of the armature, 3-phase power is obtained. Rotor houses a field coil and excited by D.C. The field coil produces flux and electromagnetic poles on the rotor surface. If the rotor is driven by an external agency, the flux linkages with three stator coils becomes sinusoidal function of time and sinusoidal voltage is induced in them. However, the induced voltages in the three coils (or phases) will differ in phase by 120° because the present value of flux linkage with R-phase coil will take place after 120° with Y-phase coil and further 120° after, with B-phase coil. A salient pole alternator has projected poles as shown in figure 2.1(a). It has non uniform air gap and is generally used where speed is low. On the other hand a non salient pole alternator has uniform air gap (figure 2.1(b)) and used when speed is high.



(a) Salient pole generator **(b) Non salient pole generator**

Figure 2.1: 3-phase generators.

Frequency, voltage & interconnected system

The frequency of the generated emf for a *p* polar generator is given by $f = \frac{p}{2} n$ where *n* is speed of the generator in rps or $f = \frac{p}{120} n$ when *n* is in rpm. Frequency of the generated voltage is standardized to 50 HZ in our country and several European countries. In USA and Canada it is 60 Hz. The following table gives the rpm at which the generators with different number of poles are to be driven in order to generate 50 Hz voltage.

Number of poles of Generator	2	4	6	8	10
rpm at which generator to be driven	3000	1500	1000	750	600

A modern power station has more than one generator and these generators are connected in parallel. Also there exist a large number of power stations spread over a region or a country. A regional power grid is created by interconnecting these stations through transmission lines. In other words, all the generators of different power stations, in a grid are in effect connected in parallel. One of the advantages of interconnection is obvious; suppose due to technical problem the generation of a plant becomes nil or less then, a portion of the demand of power in that area still can be made from the other power stations connected to the grid. One can thus avoid complete shut down of power in an area in case of technical problem in a particular station. It can be shown that in an interconnected system, with more number of generators connected in parallel, the system voltage and frequency tend to fixed values irrespective of degree of loading present in the system. This is another welcome advantage of inter connected system. Inter connected system however, is to be controlled and monitored carefully as they may give rise to *instability* leading to collapse of the system.
All electrical appliances (fans, refrigerator, TV etc.) to be connected to A.C supply are therefore designed for a supply frequency of 50 Hz. Frequency is one of the parameters which decides the quality of the supply. It is the responsibility of electric supply company to see that frequency is maintained close to 50 Hz at the consumer premises.

It was pointed out earlier that a maximum of few hundreds of volts (say about 600 to 700 V) could be developed in a D.C generator, the limitation is imposed primarily due to presence of commutator segments. In absence of commutators, present day generated voltage in alternator is much higher, typically around 10 kV to 15 kV. It can be shown that rms voltage induced in a coil is proportional to ϕ and n i.e., $E_{coil} \propto \phi\, n$ where ϕ is the flux per pole and n is speed of the alternator. This can be justified by intuition as well: we know that mere rotating a coil in absence of magnetic flux (ϕ) is not going to induce any voltage. Also presence of flux without any rotation will fail to induce any voltage as you require rate of change of flux linkage in a coil. To control the induced voltage one has to control the d.c field current as speed of the alternator gets fixed by frequency constrain.

2.4 Thermal, hyddel & nuclear power stations

In this section we briefly outline the basics of the three most widely found generating stations – thermal, hydel and nuclear plants in our country and elsewhere.

2.4.1 Thermal plant

We have seen in the previous section that to generate voltage at 50 Hz we have to run the generator at some fixed rpm by some external agency. A turbine is used to rotate the generator. Turbine may be of two types, namely steam turbine and water turbine. In a thermal power station coal is burnt to produce steam which in turn, drives the steam turbine hence the generator (turbo set). In figure 2.2 the elementary features of a thermal power plant is shown.

In a thermal power plant coil is burnt to produce high temperature and high pressure steam in a boiler. The steam is passed through a steam turbine to produce rotational motion. The generator, mechanically coupled to the turbine, thus rotates producing electricity. Chemical energy stored in coal after a couple of transformations produces electrical energy at the generator terminals as depicted in the figure. Thus proximity of a generating station nearer to a coal reserve and water sources will be most economical as the cost of transporting coal gets reduced. In our country coal is available in abundance and naturally thermal power plants are most popular. However, these plants pollute the atmosphere because of burning of coals.

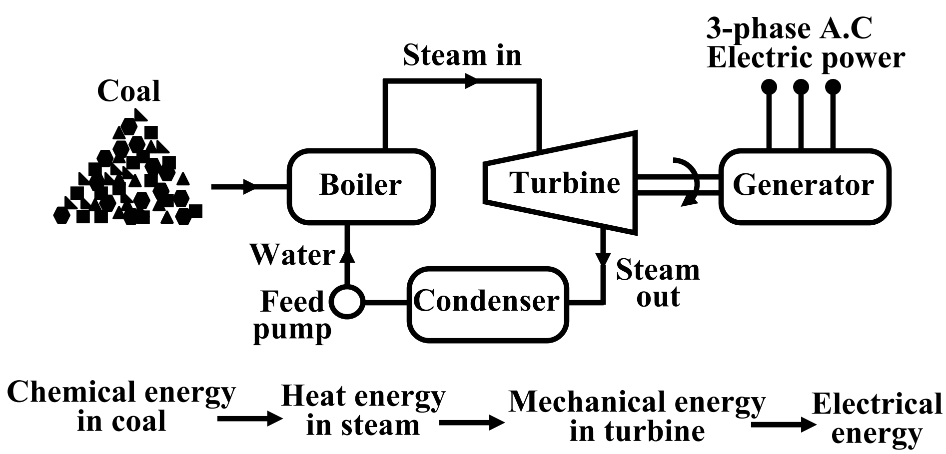


Figure 2.2: Basic components of a thermal generating unit.

Stringent conditions (such as use of more chimney heights along with the compulsory use of electrostatic precipitator) are put by regulatory authorities to see that the effects of pollution is minimized. A large amount of ash is produced every day in a thermal plant and effective handling of the ash adds to the running cost of the plant. Nonetheless 57% of the generation in out country is from thermal plants. The speed of alternator used in thermal plants is 3000 rpm which means 2-pole alternators are used in such plants.

2.4.2 Hydel plants

In a hydel power station, water head is used to drive water turbine coupled to the generator. Water head may be available in hilly region naturally in the form of water reservoir (lakes etc.) at the hill tops. The potential energy of water can be used to drive the turbo generator set installed at the base of the hills through piping called *pen stock*. Water head may also be created artificially by constructing dams on a suitable river. In contrast to a thermal plant, hydel power plants are eco-friendly, neat and clean as no fuel is to be burnt to produce electricity. While running cost of such plants are low, the initial installation cost is rather high compared to a thermal plants due to massive civil construction necessary. Also sites to be selected for such plants depend upon natural availability of water reservoirs at hill tops or availability of suitable rivers for constructing dams. Water turbines generally operate at low rpm, so number of poles of the alternator are high. For example a 20-pole alternator the rpm of the turbine is only 300 rpm.

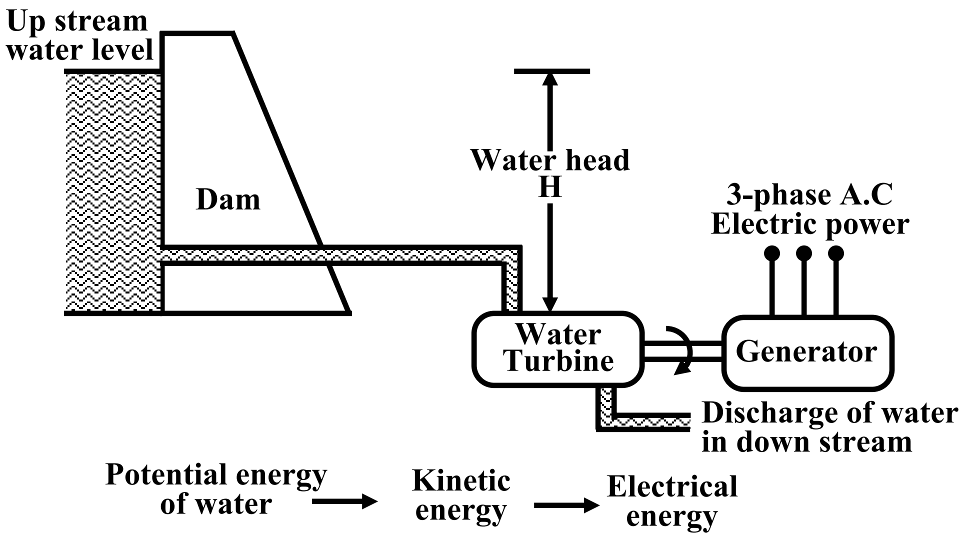


Figure 2.3: Basic components of a hydel generating unit.

2.4.3 Nuclear plants

As coal reserve is not unlimited, there is natural threat to thermal power plants based on coal. It is estimated that within next 30 to 40 years, coal reserve will exhaust if it is consumed at the present rate. Nuclear power plants are thought to be the solution for bulk power generation. At present the installed capacity of unclear power plant is about 4300 MW and expected to expand further in our country. The present day atomic power plants work on the principle of nuclear fission of ^{235}U. In the natural uranium, ^{235}U constitutes only 0.72% and remaining parts is constituted by 99.27% of ^{238}U and only about 0.05% of ^{234}U. The concentration of ^{235}U may be increased to 90% by gas diffusion process to obtain enriched ^{235}U. When ^{235}U is bombarded by neutrons a lot of heat energy along with additional neutrons are produced. These new neutrons further bombard ^{235}U producing more heat and more neutrons. Thus a chain reaction sets up. However this reaction is allowed to take place in a controlled manner inside a closed chamber called nuclear reactor. To ensure sustainable chain reaction, moderator and control rods are used. Moderators such as heavy water (deuterium) or very pure carbon ^{12}C are used to reduce the speed of neutrons. To control the number neutrons, control rods made of cadmium or boron steel are inserted inside the reactor. The control rods can absorb neutrons. If we want to decrease the number neutrons, the control rods are lowered down further and vice versa. The heat generated inside the reactor is taken out of the chamber with the help of a coolant such as liquid sodium or some gaseous fluids. The coolant gives up the heat to water in heat exchanger to convert it to steam as shown in figure 2.4. The steam then drives the turbo set and the exhaust steam from the turbine is cooled and fed back to the heat exchanger with the help of water feed pump. Calculation shows that to produce 1000 MW of electrical power in coal based thermal plant, about 6×10^6 Kg of coal is to be burnt daily while for the same amount of power, only about 2.5 Kg of ^{235}U is to be used per day in a nuclear power stations.

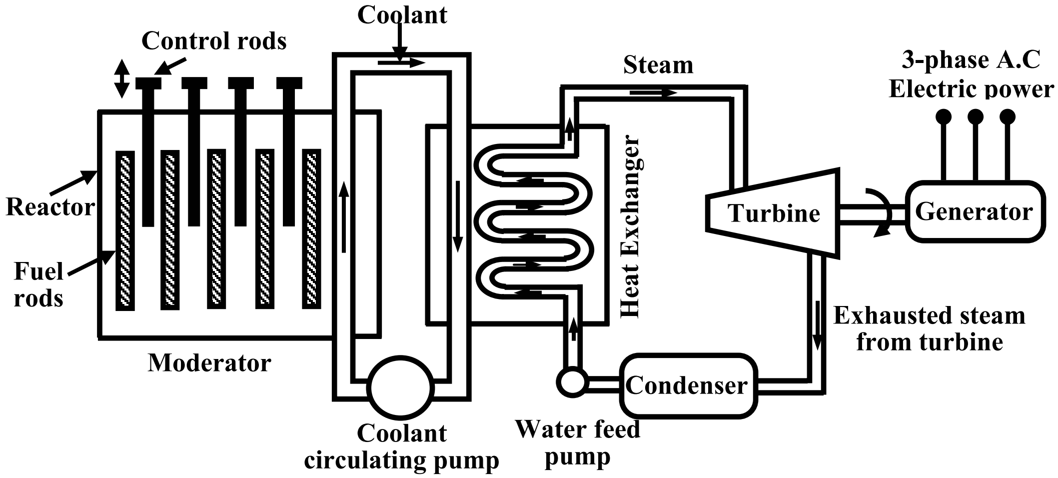


Figure 2.4: Nuclear power generation.

The initial investment required to install a nuclear power station is quite high but running cost is low. Although, nuclear plants produce electricity without causing air pollution, it remains a dormant source of radiation hazards due to leakage in the reactor. Also the used fuel rods are to be carefully handled and disposed off as they still remain radioactive.

The reserve of ^{235}U is also limited and can not last longer if its consumption continues at the present rate. Naturally search for alternative fissionable material continues. For example, plutonium (^{239}Pu) and (^{233}U) are fissionable. Although they are not directly available. Absorbing neutrons, ^{238}U gets converted to fissionable plutonium ^{239}Pu in the atomic reactor described above. The used fuel rods can be further processed to extract ^{239}Pu from it indirectly increasing the availability of fissionable fuel. Effort is also on to convert thorium into fissionable ^{233}U. Incidentally, India has very large reserve of thorium in the world.

Total approximate generation capacity and Contribution by thermal, hydel and nuclear generation in our country are given below.

Method of generation	in MW	% contribution
Thermal	77 340	69.4
Hydel	29 800	26.74
Nuclear	2 720	3.85
Total generation	1 11 440	-

Non conventional sources of energy

The bulk generation of power by thermal, hydel and nuclear plants are called conventional methods for producing electricity. Search for newer avenues for harnessing eco friendly electrical power has already begun to meet the future challenges of meeting growing power demand. Compared to conventional methods, the capacity in terms of MW of each non-conventional plant is rather low, but most of them are eco friendly and self sustainable. Wind power, solar power, MHD generation, fuel cell and power from tidal waves are some of the promising alternative sources of energy for the future.

2.5 Transmission of power

The huge amount of power generated in a power station (hundreds of MW) is to be transported over a long distance (hundreds of kilometers) to load centers to cater power to consumers with the help of transmission line and transmission towers as shown in figure 2.5.

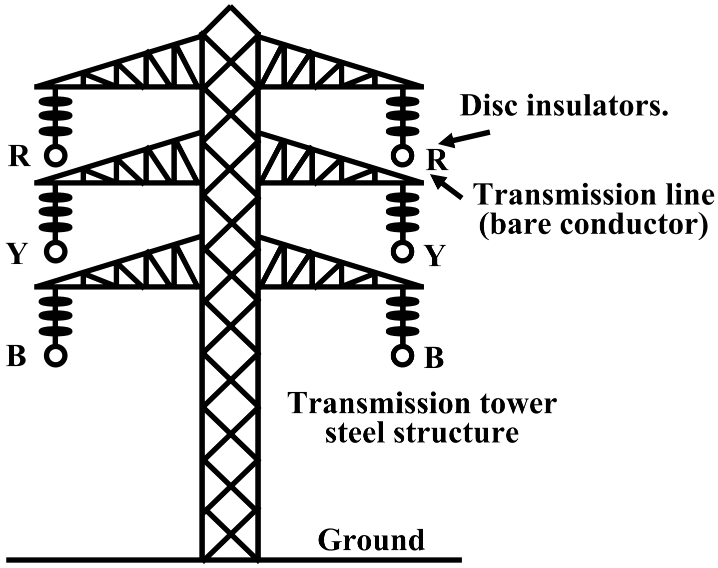


Figure 2.5: Transmission tower.

To give an idea, let us consider a generating station producing 120 MW power and we want to transmit it over a large distance. Let the voltage generated (line to line) at the alternator be 10 kV. Then to transmit 120 MW of power at 10 kV, current in the transmission line can be easily calculated by using power formula circuit (which you will learn in the lesson on A.C circuit analysis) for 3-phases follows:

$$I = \frac{P}{\sqrt{3}\, V_L \cos\theta} \text{ where } \cos\theta \text{ is the power factor}$$

$$= \frac{120\times10^6}{\sqrt{3}\times10\times10^3\times0.8}$$

$$\therefore I = 8660 \text{ A}$$

Instead of choosing 10 kV transmission voltage, if transmission voltage were chosen to be 400 kV, current value in the line would have been only 261.5 A. So sectional area of the transmission line (copper conductor) will now be much smaller compared to 10 kV transmission voltage. In other words the cost of conductor will be greatly reduced if power is transmitted at higher and higher transmission voltage. The use of higher voltage (hence lower current in the line) reduces voltage drop in the line resistance and reactance. Also transmission losses is reduced. Standard transmission voltages used are 132 kV or 220 kV or 400 kV or 765 kV depending upon how long the transmission lines are.

Therefore, after the generator we must have a step up transformer to change the generated voltage (say 10 kV) to desired transmission voltage (say 400 kV) before transmitting it over a long distance with the help of transmission lines supported at regular intervals by transmission towers. It should be noted that while magnitude of current decides the cost of copper, level of voltage decides the cost of insulators. The idea is, in a spree to reduce the cost of copper one can not indefinitely increase the level of transmission voltage as cost of insulators will offset the reduction copper cost. At the load centers voltage level should be brought down at suitable values for supplying different types of consumers. Consumers may be (1) big industries, such as steel plants, (2) medium and small industries and (3) offices and domestic consumers. Electricity is purchased by different consumers at different voltage level. For example big industries may purchase power at 132 kV, medium and big industries purchase power at 33 kV or 11 kV and domestic consumers at rather low voltage of 230V, single phase. Thus we see that 400 kV transmission voltage is to be brought down to different voltage levels before finally delivering power to different consumers. To do this we require obviously step down transformers.

Substations

Substations are the places where the level of voltage undergoes change with the help of transformers. Apart from transformers a substation will house switches (called circuit breakers), meters, relays for protection and other control equipment. Broadly speaking, a big substation will receive power through incoming lines at some voltage (say 400 kV) changes level of voltage (say to 132 kV) using a transformer and then directs it out wards through outgoing lines. Pictorially such a typical power system is shown in figure 2.6 in a short of block diagram. At the lowest voltage level of 400 V, generally 3-phase, 4-wire system is adopted for domestic connections. The fourth wire is called the neutral wire (N) which is taken out from the common point of the star connected secondary of the 6 kV/400 V distribution transformer.

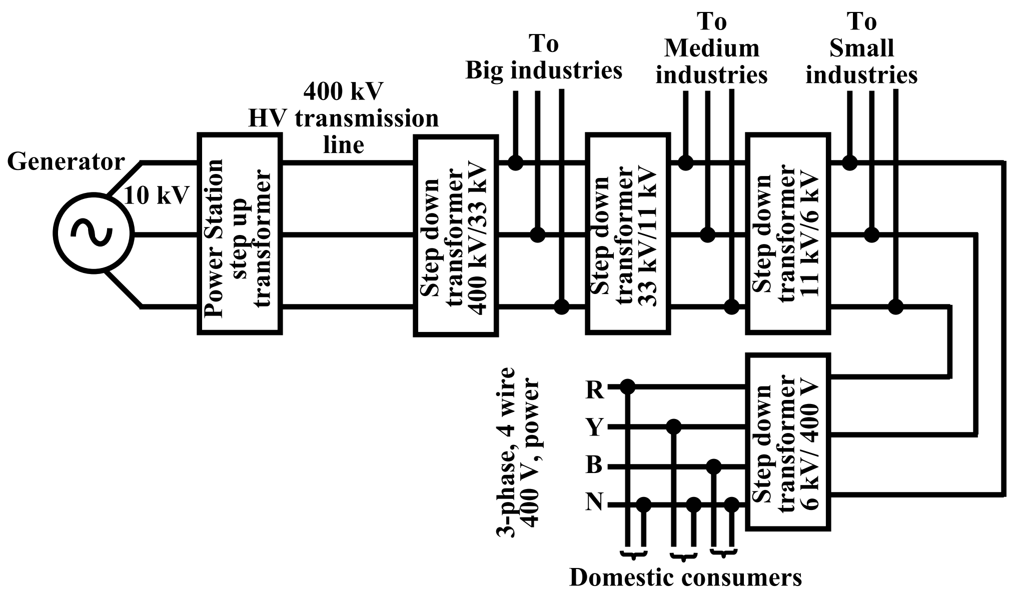


Figure 2.6: Typical voltage levels in a power system.

Some important components/equipments in substation

As told earlier, the function of a substation is to receive power at some voltage through incoming lines and transmit it at some other voltage through outgoing lines. So the most important equipment in a substation is transformer(s). However, for flexibility of operation and protection transformer and lines additional equipments are necessary.

Suppose the transformer goes out of order and maintenance work is to be carried out. Naturally the transformer must be isolated from the incoming as well as from the outgoing lines by using special type of heavy duty (high voltage, high current) switches called *circuit breakers*. Thus a circuit breaker may be closed or opened manually (functionally somewhat similar to switching on or off a fan or a light whenever desired with the help of a ordinary switch in your house) in substation whenever desired. However unlike a ordinary switch, a circuit breaker must also operate (i.e., become opened) *automatically* whenever a fault occurs or overloading takes place in a feeder or line. To achieve this, we must have a current sensing device called CT (current transformer) in each line. A CT simply steps down the large current to a proportional small secondary current. Primary of the CT is connected in series with the line. A 1000 A/5 A CT will step down the current by a factor of 200. So if primary current happens to be 800 A, secondary current of the CT will be 4 A.

Suppose the rated current of the line is 1000 A, and due to any reason if current in the line exceeds this limit we want to operate the circuit breaker automatically for disconnection.

In figure 2.7 the basic scheme is presented to achieve this. The secondary current of the CT is fed to the relay coil of an *overcurrent relay*. Here we are not going into constructional and operational details of a over current relay but try to tell how it functions. Depending upon the strength of the current in the coil, an ultimately an electromagnetic torque acts on an aluminum disc restrained by a spring. Spring tension is so adjusted that for normal current, the disc does not move. However, if current exceeds the normal value, torque produced will overcome the spring tension to rotate the disc about a vertical spindle to which a long arm is attached. To the arm a copper strip is attached as shown figure 2.8. Thus the arm too will move whenever the disk moves.

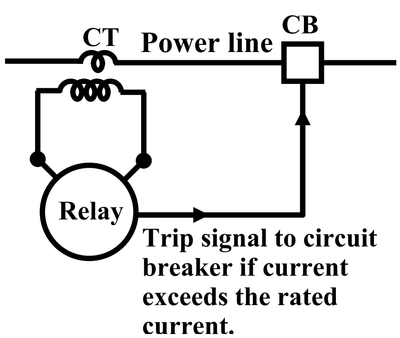


Figure 2.7: Basic scheme of protection.

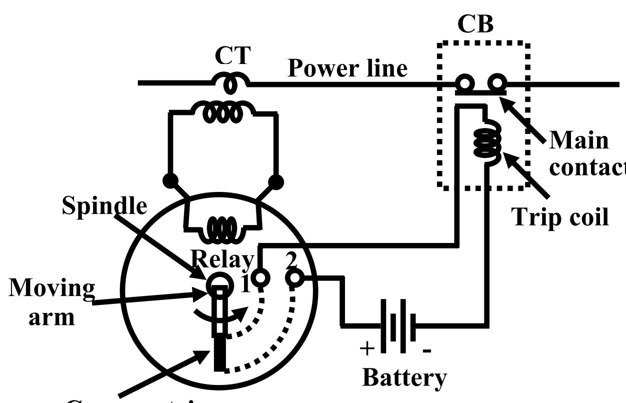


Figure 2.8: Relay and CB.

The relay has a pair of *normally opened* (NO) contacts 1 & 2. Thus, there will exist open circuit between 1 & 2 with normal current in the power line. However, during fault condition in the line or overloading, the arm moves in the anticlockwise direction till it closes the terminals 1 & 2 with the help of the copper strip attached to the arm as explained pictorially in the figure 2.8. This short circuit between 1 & 2 completes a circuit comprising of a battery and the *trip* coil of the circuit breaker. The opening and closing of the main contacts of the circuit breaker depends on whether its trip coil is energized or not. It is interesting to note that trip circuit supply is to be made independent of the A.C supply derived from the power system we want to protect. For this reason, we expect batteries along with battery charger to be present in a substation.

Apart from above there will be other types of protective relays and various meters indicating current, voltage, power etc. To measure and indicate the high voltage (say 6 kV) of the line, the voltage is stepped down to a safe value (say 110V) by transformer called *potential transformer*

(PT). Across the secondary of the PT, MI type indicating voltmeter is connected. For example a voltage rating of a PT could be 6000 V/110 V. Similarly, Across the secondary we can connect a low range ammeter to indicate the line current.

2.6 Single line representation of power system

Trying to represent a practical power system where a lot of interconnections between several generating stations involving a large number of transformers using three lines corresponding to R, Y and B phase will become unnecessary clumsy and complicated. To avoid this, a single line along with some symbolical representations for generator, transformers substation buses are used to represent a power system rather neatly. For example, the system shown in 2.6 with three lines will be simplified to figure 2.9 using single line.

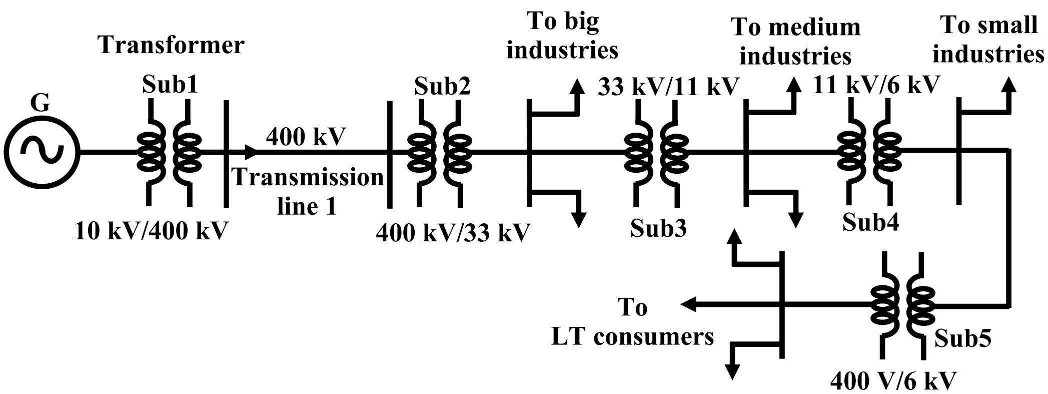


Figure 2.9: Single line representation of power system.

As another example, an interconnected power system is represented in the self explained figure 2.10 – it is hoped that you understand the important features communicated about the system through this figure.

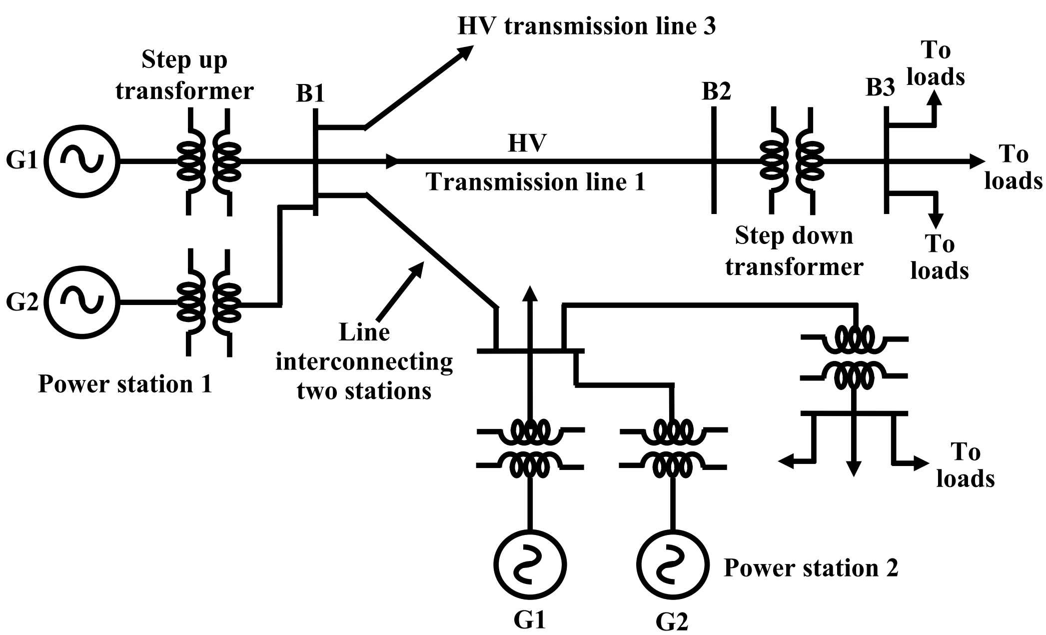


Figure 2.10: Single line representation of power system.

2.7 Distribution system

Till now we have learnt how power at somewhat high voltage (say 33 kV) is received in a substation situated near load center (a big city). The loads of a big city are primarily residential complexes, offices, schools, hotels, street lighting etc. These types of consumers are called LT (low tension) consumers. Apart from this there may be medium and small scale industries located in the outskirts of the city. LT consumers are to be supplied with single phase, 220 V, 40 Hz. We shall discuss here how this is achieved in the substation receiving power at 33 kV. The scheme is shown in figure 2.11.

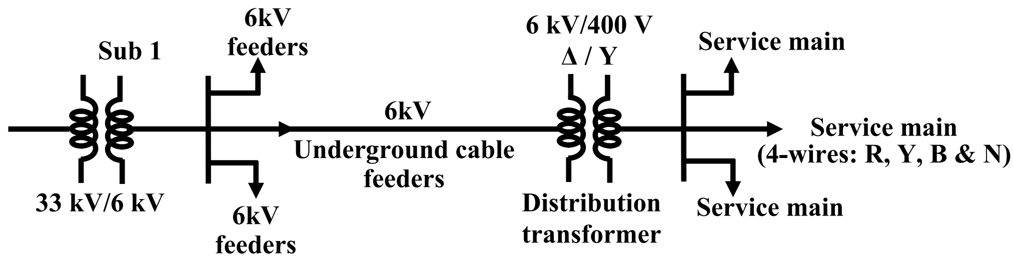


Figure 2.11: Typical Power distribution scheme.

Power receive at a 33 kV substation is first stepped down to 6 kV and with the help of under ground cables (called feeder lines), power flow is directed to different directions of the city. At the last level, step down transformers are used to step down the voltage form 6 kV to 400 V. These transformers are called distribution transformers with 400 V, star connected secondary. You must have noticed such transformers mounted on poles in cities beside the roads. These are called pole mounted substations. From the secondary of these transformers 4 terminals (R, Y, B and N) come out. N is called the neutral and taken out from the common point of star connected secondary. Voltage between any two phases (i.e., R-Y, Y-B and B-R) is 400 V and between any phase and neutral is 230 V$\left(=400/\sqrt{3}\right)$. Residential buildings are supplied with single phase 230V, 50Hz. So individual are to be supplied with any one of the phases and neutral. Supply authority tries to see that the loads remain evenly balanced among the phases as far as possible. Which means roughly one third of the consumers will be supplied from R-N, next one third from Y-N and the remaining one third from B-N. The distribution of power from the pole mounted substation can be done either by (1) overhead lines (bare conductors) or by (2) underground cables. Use of overhead lines although cheap, is often accident prone and also theft of power by hooking from the lines take place. Although costly, in big cities and thickly populated areas underground cables for distribution of power, are used.

2.8 Conclusion

In this lesson, a brief idea of generation, transmission and distribution of electrical power is given - which for obvious reason is neither very elaborative nor exhaustive. Nonetheless, it gives a reasonable understanding of the system for a beginner going to undertake the course on electrical technology. If you ever get a chance to visit a substation or power station – don't miss it.

Some basic and important points, in relation to a modern power system, are summarized below:

1. Generation, transmission and distribution of electric power in our country is carried out as 3-phase system at 50 Hz.
2. Three most important conventional methods of power generation in out country are: coal based thermal plants, Hydel plants and nuclear plants.
3. Load centers (where the power will be actually consumed) are in general situated far away from the generating station. So to transmit the large amount of power (hundreds of MW) efficiently and economically over long distance, high transmission voltage (such as 400 kV, 220 kV) is used.
4. Material used for transmission lines is bare is bare copper conductors which are supported at regular intervals by steel towers. Stack of disk type ceramic insulators are used between the HV line and the steel tower.
5. Level of current decides the section of the line conductor and the level of voltage decides the amount of insulation required.

2.9 Answer the following

1. Name three conventional ways of generating power. Of these three, which one contributes maximum generation in India.
2. What number of phases and frequency are adopted to generate, transmit and distribute electrical power in modern power system?
3. Name the types of generators (alternators) used in (1) thermal plant and (2) in hydel power plant.
4. In a hydel power station, the number of poles of an alternator is 24. At what rpm the alternator must be driven to produce 50 Hz voltage?
5. Give some typical value of generated voltage in a power station. Why is it necessary to step up the voltage further before transmitting?
6. What is a substation? What important equipments are found in a substation?
7. With the help of a schematic diagram explain how a overcurrent relay protects a line during short circuit fault.
8. What are the functions of CT and PT in a substation?
9. The ammeter reading connected across a CT secondary is 3 A and the voltage reading connected across a PT is 90 V. If the specification of the CT and PT are respectively 1000 A/5 A and 6.6 kV/110 V, What is the actual current and voltage of the line?
10. What is a pole mounted substation? At what voltage levels are the found in a power system?
11. Why are batteries used in a substation.
12. Are different power stations interconnected? If so, why?
13. What are the differences between a coal based thermal plant and a nuclear power plant.